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Effects of introduced exotic tree species on Collembola communities: the importance of management techniques

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Summary. Studies of the impact of the substitution of autochthonous forests by plantations of exotic tree species (a quite common phenomenon in Southern European countries) on soil arthropod communities (mainly Collembola and Acarina) generally deal with the effects of the exotic species *per se* and disregard the management techniques used. In this study the impact of the introduced *Eucalyptus globulus* on the Collembola communities of *Quercus ilex ballota* and *Quercus suber* stands was analysed. Since the autochthonous tree species are similar (in terms of leaf type and the ability to produce litter) the main objective was to examine the effects of the different management techniques used in the two plantations of *Eucalyptus*. (i) There is a significant difference in management techniques used in the *Eucalyptus* plantations leading to differences in habitat configuration: the plantation associated with the Holm-Oak stand is used for cellulose paste production, with periodic removal of the shrub and herbaceous layers; the other plantation, close to the Cork-Oak stand, is not managed at all, presenting an abundant shrub layer. (ii) In both cases, the substitution of the Oak species by *Eucalyptus* caused a disruption of the Collembola communities, although it was more pronounced in *Q. ilex ballota* vs *E. globulus* (station 1) than in *Q. suber* vs *E. globulus* (station 2). The number of individuals, the number of taxa and diversity parameters are in most cases greater under Oak species but more evident in station 1. (iii) Given these results, the influence of the factor "management technique-habitat configuration" in analysing and interpreting effects of exotics on soil arthropod communities is discussed.

Key words: Collembola community disruption, *Eucalyptus*, *Quercus*, Forest practices

Introduction

The effects of reafforestation practices on soil arthropod fauna are dependent on several factors: (i) the nature of the tree species used in the process (native or exotic), (ii) the management techniques used to install and to manage the plantation and (iii) the previous history of the reafforestated area (Deharveng 1996). The majority of the studies which have examined these effects have dealt with the first point, generally neglecting, the information concerning the other two (Bonnet et al. 1976, 1979; Arbea & Jordana 1985; Gama et al. 1991; Vasconcelos et al. 1994).

In this study the responses of soil Collembola communities to the replacement of stands of holm-oak (*Quercus ilex ballota*) and cork-oak (*Q. suber*) with the exotic species *Eucalyptus*

globulus are examined. The use of this allochthonous tree species in the reafforestation programme is considered the second most important ecological disturbance on Portuguese forests (after forest fires) and plantations of this species account for 17 % of the forested area. Here not only the importance of the first point in discussing the results is stressed, but attention is focused on the different forestry management techniques adopted.

Material and Methods

Site description

The study was carried out at 2 sets of contiguous stations: holm-oak and eucalyptus 1 (located in the province of Castelo Branco, inner centre Portugal) and cork-oak and eucalyptus 2 (located in Santarém province also in the central part of Portugal, but Southwest of the first two stations).

The holm-oak forest had a dense shrub layer dominated by *Cistus ladanifer*, *C. salvifolius* and *Lavandula stoechas*. Oaks appeared both as mature trees (aged more than 30 years) and young plants, contributing to the thickness of the shrub layer. The entire site presented a constant leaf cover, which was particularly homogeneous below trees. The soil in the eucalyptus 1 stand showed signs of intense management (soil was heavily rotavated and mixed), and had sparse vegetation cover. Oak was replaced by eucalyptus trees (aged about 10 years) planted in grooves opened along lines perpendicular to the slope. In some sampling quadrats there was some accumulation of eucalyptus leaves and bark on those grooves. Since this plantation is exploited for commercial purposes, every two years all the shrub and herbaceous vegetation and all the standing stock biomass is removed.

In the cork-oak stand the vegetation cover was quite heterogeneous, with specimens of *Q. suber* (aged approximately 30 years) distributed in a non regular way. Shrub and herbaceous layers (mainly dominated by *Chamaespartium tridentatum*, *Cistus salvifolius*, *Calluna vulgaris*, *Lavandula stoechas* and *Lithodora prostrata*) were closely associated with the presence of trees, and were thus distributed heterogeneously. In some sampling quadrats there was some accumulation of leaves and branches of cork-oak. In the eucalyptus 2 stand, the vegetation cover was very dense. Trees (2nd rotation, aged 22 years) were not distributed in a regular way, indicating the absence of a specific technique during the instalation of the plantation. The fact that this stand was not exploited for commercial purposes, with disturbances being limited to clear cutting times (every 10–12 years), lead to the development of an abundant shrub cover (with the same dominant species found in the *Q. suber* station). In addition, the soil had a deep litter layer, composed of eucalyptus leaves, branches and bark.

There were marked differences between the physical and chemical properties of the holm-oak and eucalyptus 1 stations (Table 1), particularly at the humus horizon level. This can be attributed to the level of anthropogenic influence in the eucalyptus stand. The management techniques used in planting and running the stand lead to decreased humus horizon thickness, moisture and nutrient content, and contribute to an impoverishment of the soil.

In the cork-oak and eucalyptus 2 stands the picture was completely different. The absence of anthropogenic disturbance over the 10 years in which the stand was in existence meant that most physical and chemical parameters were simplar at the two stations.

Sampling, soil characterization and fauna extraction

Sampling was carried out in Spring 1992. At each stand 4 quadrats (8 m per 8 m) were selected at random and divided in 16 small squares (2 m per 2 m). Inside each quadrat, 4 squares were then randomly selected, making a total of 16 sampling squares per site. After a careful removal of the leaf layer, two samples (250 cc. each, area of 100 cm^2) were taken at different depths in each square, one in the organic horizon (designated by humus horizon or humus) and the other in the mineral horizon (designated by soil). Simultaneously, soil temperature and organic horizon thickness were measured. To catch epigeic fauna, a pitfall trap (a plastic vial 2 cm of diameter) was placed in each sampling square for one week.

Fauna was extracted by means of Berlese-Tullgren funnels. The Collembola obtained with both dynamic extraction and pitfall traps were identified to the species level. After extraction, the dried samples were gently crushed and sieved through a 2 mm sieve and four aliquots were separated for analysis. Water content (expressed in terms of percentage of water in relation to dry weight at 105 °C), organic matter content (expressed as Ash Free Dry Weight), carbon and nitrogen contents (measured by Anne's and Kjeldahl's methods respectively) and pH (measured in water (1:6 v/v) at 20 °C) were all measured according to Dewis & Freitas (1984).

Table 1. Physical and chemical characterization of the sampling stations (means ± SD), nested ANOVA significance values are also indicated

	Q. ilex ballota	*E. globulus 1*	Sig. values (p)
Humus hoZ. thickness (cm)	2.6 ± 0.9	1.9 ± 0.5	*
Soil temperature (°C)	12 ± 1.4	14.2 ± 2.3	**
Soil pH	6.66 ± 0.38	5.63 ± 0.18	***
Humus hor. water content (%)	24.65 ± 9.35	12.22 ± 5.56	*
Soil water content (%)	17.51 ± 5.53	14.9 ± 5.21	n.s.
Humus hor. carbon content (%)	4.71 ± 1.23	1.98 ± 0.84	**
Soil Carbon content (%)	2.29 ± 0.64	1.78 ± 0.6	n.s.
Humus hor. nitrogen content (%)	0.34 ± 0.11	0.13 ± 0.06	***
Soil nitrogen content (%)	0.2 ± 0.05	0.13 ± 0.07	*
Humus hor. C/N ratio	14.52 ± 3.19	15.73 ± 5.02	n.s.
Soil C/N ratio	11.77 ± 3.36	15.73 ± 5.02	n.s.
Humus hor. org. matter content (%)	11.76 ± 2.67	4.81 ± 1.04	***
Soil org. matter content (%)	6.37 ± 1.23	4.81 ± 1.04	*

	Q. suber	*E. globulus 2*	Sig. values (p)
Humus hoZ. thickness (cm)	0.9 ± 0.4	0.7 ± 0.3	n.s.
Soil temperature (°C)	18.5 ± 2.16	19.13 ± 2.09	n.s.
Soil pH	6.19 ± 0.79	6.25 ± 0.89	n.s.
Humus hor. water content (%)	10.01 ± 8.44	13.01 ± 15.43	n.s.
Soil water content (%)	6.57 ± 3.41	3.57 ± 0.85	n.s.
Humus hor. carbon content (%)	15.57 ± 10.57	32.13 ± 11.19	*
Soil Carbon content (%)	4.42 ± 2.01	2.3 ± 0.52	n.s.
Humus hor. nitrogen content (%)	0.67 ± 0.42	0.92 ± 0.36	n.s.
Soil nitrogen content (%)	0.22 ± 0.11	0.13 ± 0.14	n.s.
Humus hor. C/N ratio	24.91 ± 14.84	36.27 ± 11.74	n.s.
Soil C/N ratio	22.06 ± 6.12	23.72 ± 9.8	n.s.
Humus hor. org. matter content (%)	31.45 ± 23.63	53.27 ± 17.58	n.s.
Soil org. matter content (%)	8.2 ± 4.14	4.03 ± 1.04	*

n.s. – non significant; * – $p < 0.05$; ** – $p < 0.01$; *** – $p < 0.001$

Data analysis

Physical and chemical parameters were compared using a nested ANOVA. Prior to analysis data were transformed: transformations were applied depending how each variable was expressed (Asin$\sqrt{x}$ for percentage values and ratios, log(x) for the other variables) (Zar 1984). Numbers of individuals and numbers of taxa on paired stations were also compared using a nested ANOVA following log (x+1) transformation.

Differences in Collembola community composition between contiguous sites were evaluated using either diversity or similarity measures. Species diversity, evenness and species richness were calculated for the different strata inside each site (samples were cumulated for each stratum) using the Shannon-Weaver, Pielou and Margalef indices respectively. Diversity values were then compared by a t-test after Hutcheson 1970 (in Magurran 1991).

In the second group of analysis, and as a way to associate statistical power to the comparative analysis of both communities, the Bray-Curtis coefficient, selected for its robustness in analysing ecological data (Faith et al. 1987), was used to measure similarity between native and the correspondent eucalyptus plantation samples using the SIMAN approach (Sousa & Gama 1994). A similar approach was used to evaluate which of the pairs of stations studied was the most affected by the substitution of the native species by the exotic one. In this case the average dissimilarity values from each group of native vs. exotic stand were compared using a t-test. Bray-Curtis coefficient was also used in this case; data transformation followed the same steps as described above.

Results

The shift from the native tree species to the eucalyptus lead to different responses at the two *Quercus* stations (Fig. 1). At the first pair of stations (holm-oak vs. eucalyptus 1) all the measured parameters were larger under the native species ($p < .05$). There was a reduction in the number of Collembola species (Fig. 1b), in diversity (Fig. 1c) and species richness values (Fig. 1e).

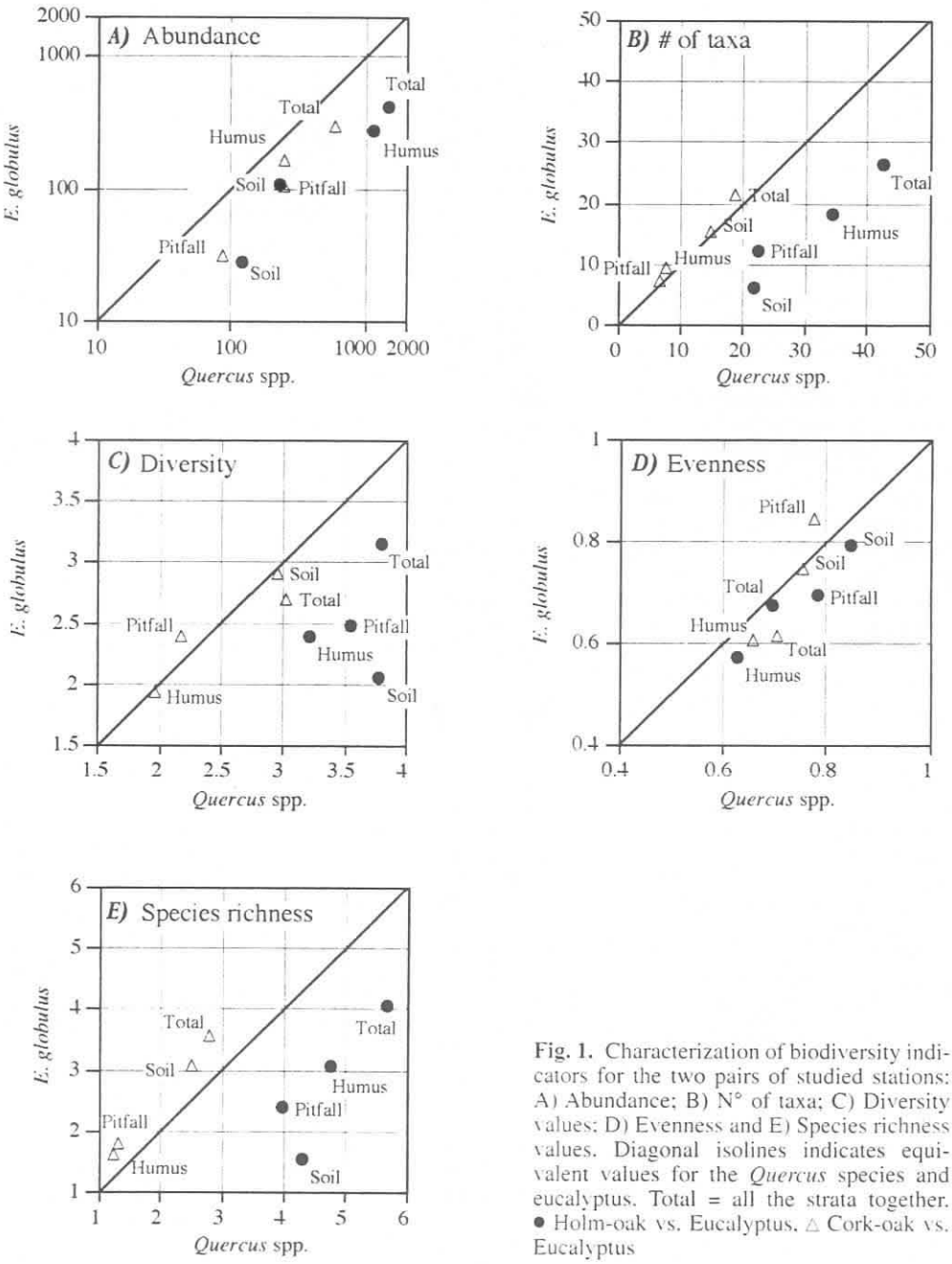

Fig. 1. Characterization of biodiversity indicators for the two pairs of studied stations: A) Abundance; B) N° of taxa; C) Diversity values; D) Evenness and E) Species richness values. Diagonal isolines indicates equivalent values for the *Quercus* species and eucalyptus. Total = all the strata together. ● Holm-oak vs. Eucalyptus, △ Cork-oak vs. Eucalyptus

Table 2. Collembola abundance and number of taxa for the holm-oak and eucalyptus 1 stations

Taxa	*Quercus ilex ballota*				*Eucalyptus globulus 1*			
	Soil	Humus	"Pitfall"	Total	Soil	Humus	"Pitfall"	Total
Ceratophysella engadinensis (Gisin, 1949)	23	90	2	115	3	25		28
Hypogastrura affinis (Schäffer, 1900)		1	1	2				
Microgastrura duodecimoculata Stach, 1922		5		5				
Microgastrura sensiliata (Jordana, 1981)			55	55				
Xenyllogastrura octoculata (Steiner, 1955)	2	8		10				
Brachystomella parvula (Schäffer, 1896)	20	456	6	482	11	149	4	164
Anurida pusilla Gama 1964						1		1
Anurida sp. (0+0 eyes)						1		1
Bilobella aurantiaca (Caroli, 1912)	2	1		3		15		15
Friesea ladeiroi Gama 1959	1	6		7				
Friesea steineri Simon, 1975		2		2				
Deutonura sp.		1		1				
Pseudachorutes palmiensis Börner, 1903		1	1	2	2	2		4
Pseudachorutes parvulus Börner, 1901		11		11		9		9
Superodontella carmenae Arbea et Luciñez, 1991						3		3
Mesaphorura macrochaeta Rusek, 1976	2	5		7				
Onychiurus obsiones Cassagnau, 1963	2	4		6				
Protaphorura gisini Gama, 1964	7	149		156	9	29		38
Stenaphorura quadrispina Börner, 1901	8	5		13	1			1
Cryptopygus scapelliferus (Gisin, 1955)	2	7		9				
Cryptopygus thermophilus (Axelson, 1906)	12	124		136		1		1
Isotomiella minor (Schäffer, 1896)	12	9		21				
Isotomodes quadrisetosus Gama, 1963	6	3	1	10		1		1
Isotomurus balteatus (Reuter, 1876)			8	8			1	1
Isotomurus fucicola (Reuter, 1891)	1	75	21	97	1	11		12
Isotomurus palustris bimaculatus Ågren, 1903 s. Stach, 1947			22	22				
Proisotoma gisini Gama, 1964	5	18	1	24				
Proisotoma minuta (Tullberg, 1871)	6	97	3	106				
Heteromurus major (Moniez, 1889)		2	7	9		2	4	6
Lepidocyrtus lusitanicus Gama, 1964	1	14	23	38			1	1
Lepidocyrtus sp.			3	3			55	55
Pseudosinella infrequens Gisin et Gama, 1969	1	4		5				
Pseudosinella picta (Börner, 1903)		1		1		2		2
Pseudosinella sp.						4	1	5
Entomobryidae juv.	6	10	3	19		3	5	8
Allacma fusca (L., 1758)		2		2				
Arrhopalites caecus (Tullberg, 1871)	1			1				
Bourletiella gamae Bretfeld			1	1			14	14
Caprainea bremondi (Delamare et Bassot, 1957)		3		3				
Dicyrtoma fusca (Lucas, 1842)			1	1				
Dicyrtomina ornata (Nicolet, 1841)							6	6
Dicyrtomina sp.			3	3		3	2	5
Sminthurides parvulus (Krausbauer, 1898)		24	20	44				
Sminthurinus aureus (Lubbock, 1862)		7		7				
Sminthurus multipunctatus Schäffer, 1896		3	33	36			6	6
Sminthurus sp.		14	3	17				
Sphaeridia pumilis (Krausbauer, 1898)	1	27	23	51		2		2
Sminthuridae juv.	4	6	1	11			7	7

Table 2. (cont.) Collembola abundance and number of taxa for the cork-oak and eucalyptus 2 stations

Taxa	*Quercus suber*				*Eucalyptus globulus 2*			
	Soil	Humus	"Pitfall"	Total	Soil	Humus	"Pitfall"	Total
Ceratophysella armata (Nicolet, 1841)					3			3
Ceratophysella tergilobata (Cassagnau, 1954)					5	2		7
Ceratophysella juv.	15			15				
Xenylla brevisimilis mediterranea Gama, 1964	48	146	1	195	41	98	5	144
Xenylla franzi Steiner, 1955	6			6				
Xenylla schillei Börner, 1902	1			1				
Bilobella aurantiaca (Caroli, 1912)	3			3	2	4		6
Deutonura centralis (Gama, 1964)					1			1
Friesea mirabilis Tullberg, 1871					1			1
Micranurida (2+2 eyes) pig.					1			1
Mesaphorura sp.					2			2
Protaphorura armata Tullberg, 1869	16			16	12			12
Cryptopygus scapelliferus (Gisin, 1955)	8			8				
Cryptopygus thermophilus (Axelson, 1900)	88			88	2			2
Isotoma notabilis Schäffer, 1896	6	26		32				
Isotomurus fucicola (Reuter, 1891)					2			2
Proisotoma minuta (Tullberg, 1871)	2			2	5	20		25
Tetracanthella hygropetrica Cassagnau, 1954		1		1				
Entomobrya multifasciata (Tullberg, 1871)	8	33	27	68	6	4	7	17
Entomobrya nivalis (L., 1758)			2	2				
Heteromurus major (Moniez, 1889)	1		14	15	2	14		16
Lepidocyrtus lusitanicus Gama, 1964	31	33	24	88				
Lepidocyrtus cyaneus Tullberg, 1871							1	1
Pseudosinella infrequens Gisin et Gama, 1969	4	9		13		1		1
Pseudosinella sp.		1		1				
Entomobryidae juv.	16	11	22	49	17	13	10	40
Arrhopalites furcatus Stach, 1945						3		3
Bourletiella sp.							1	1
Prorastriopes quinquefasciatus (Krausbauer, 1898)			1	1			5	5
Sminthurinus bimaculatus (Axelson, 1902)							1	1

SIMAN analysis (Fig. 2a) also showed the disturbance of the Collembola community structure, with the t-test on similarity data revealing significant differences between 'control' and 'treatment' groups ($p < 0.001$) (the exception in the mineral horizon is due to the great variability of similarity values causing a decrease in the 't' value and a non significant difference between both groups). There was an impoverishment of the collembola community associated with the eucalyptus 1 stand (Table 2). The most important fact observed was the reduction in the number of individuals (or disappearance) of certain species, belonging mainly to the Isotomidae and Hypogastruridae (e.g. *Microgastrura sensiliata* (Jordana), *Cryptopygus thermophilus* (Axelson), *Isotomurus fucicola* (Reuter), *I. palustris bimaculatus* (Ågren), *Proisotoma gisini* Gama, *Proisotoma minuta* (Tullberg)), and an increase in representativity of the Entomobryidae and Symphypleona (e.g. *Heteromurus major* (Moniez), *Lepidocyrtus* sp., *Bourletiella gamae* Bretfeld, *Dicyrtomina ornata* (Nicolet)). The first group of taxa are typically forest species, very demanding in terms of habitat configuration and unable to cope with the new conditions existing in the plantation. The second group is characterised by high

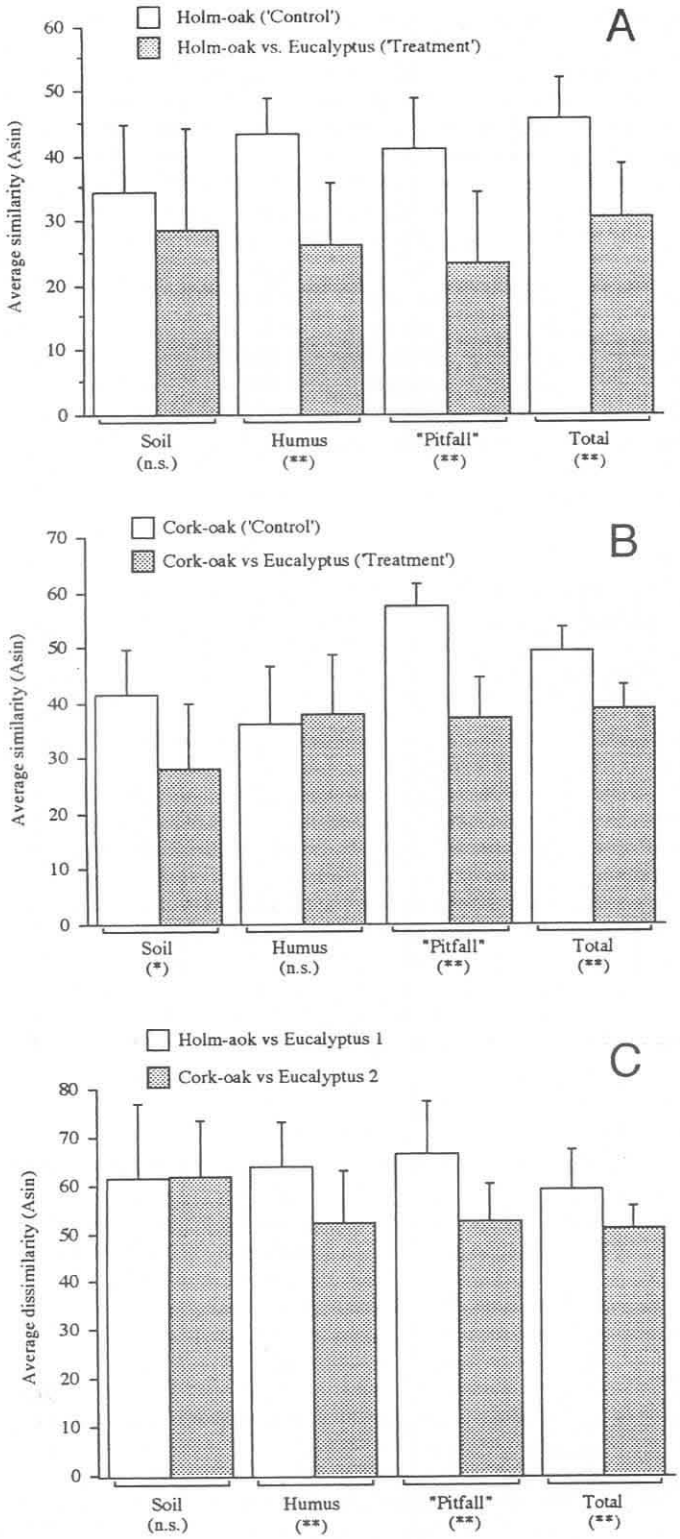

Fig. 2. SIMAN analysis on both pairs of studied stations. A and B, similarity values (average + SD) on control and treatment groups; C, dissimilarity values (average + SD) on paired stations (see text). T-test significance results are also indicated
(n.s. – non significant;
* – $p < 0.05$; ** – $p < 0.01$)

mobility and a strong capacity to adapt to new situations and an ability to colonise open habitats (Ardanaz & Jordana 1986; Luciañez et al. 1988).
At the second pair of stations (cork-oak vs. eucalyptus 2) the measured parameters were similar for both stations (Fig. 1); the number of taxa and abundance were significantly different ($P < 0.01$) only in pitfall trap samples, and the t-test for diversity values only revealed differences when all the strata were considered together ($p < 0.01$).
Even with this similarity in terms of diversity and species richness, the SIMAN analysis revealed significant differences on community structure between both groups in the majority of the strata studied (Fig. 2b). The existence (or the absence) of these differences can be related with the representative taxa at each level, either being different in the two stations when we consider soil or pitfall traps, or similar in the case of humus horizon (Table 2).
The different response caused by shifting from the native species to the exotic one is well represented in Fig. 2c. The average dissimilarity values between Collembola communities inside each pair of stations was higher for holm-oak vs eucalyptus 1 in almost all strata analysed ($p < 0.01$). This indicates that the Collembola community associated with this oak species was the most affected by the reafforestation with the eucalyptus.

Discussion

The study of both pairs of stations, where *Quercus* species can be considered equivalent in terms of supporting similar Collembola communities (both of them are evergreen species and, in this case, growing on very poor soil) and where the eucalyptus plantations were installed following different management techniques, leads us to attribute the different responses mainly to the changes in habitat configuration, particularly at the organic horizon and vegetation cover levels. These are vital to the existence of favourable microhabitat conditions for soil microarthropods (mainly in terms of food and moisture conditions).
Although at both pairs of stations a disruption on Collembola communities was observed, this was less evident in the cork-oak vs. eucalyptus stands, presumably due to the absence of disturbance. In this case both stations have a similar structure on the organic horizon and on vegetation cover.
With these observations we do not intend to diminish the importance of the nature of the planted species, but simply to emphasise the importance of the installation and management in explaining the observed effects on Collembola communities. Any reafforestation action, especially if the planted tree species is an exotic one, induces a change in the biocenotic equilibrium of soil communities. The magnitude of those disturbances is going to be conditioned by the new edaphic and climatic conditions, related not only with the characteristics of the planted species, but also with the adopted measures for the installation and management of the plantation (mainly the frequency of the interventions in the system).
Considering the binomium 'producing vs. protecting', more appropriate methods and instruments must be adopted in the management of the forested such that they cause as little disturbance of the soil surface as possible. For instance, not removing the organic matter resulting from the harvest and using methods that allow its incorporation into the soil, could diminish some existing problems like the decrease in water retention and the increase of soil erosion.

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